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Prediction of the dew point pressure for gas condensate using a modified Peng–Robinson equation of state and a four-coefficient molar distribution function

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ABSTRACT

Gas condensate is mainly composed of highly valued hydrocarbons. Its high molecular weight is derived from the quantity of heavy ends. Predicting the dew point pressure of gas condensate is important in reservoir and gas transportation engineering. In this study, a thermodynamic model based on a modified Peng-Robinson equation of state is established to predict the dew point pressure. The presented model, using the MPR2 equation of state combined with a four-coefficient molar distribution function and the Kesler-Lee characterization method, is superior to four empirical correlations. This study also presents a comparison between the adopted MPR2 equation and ten equations of state, including eight PR families of equations, i.e., PR, PRSV, PRT, PRSF, PRHF, PRGF, PRTBD and PRJF, and two other modified versions of the SRK equation, i.e., SRKMCC and SRKNB. The statistical error analysis indicates that the model outperforms the other methods, with an average absolute relative error of 11.05% and a coefficient of determination of 0.829. The relative deviation range of the calculated values by the model is −0.20% −0.37%, which is in better agreement with the experimental values than the other methods employed in this study. Therefore, the presented model is effective and practical for predicting the dew point pressure for gas condensate systems.

1. Introduction

As an important part of natural gas resources, gas condensate which is mainly composed of heavy hydrocarbon fractions, has a high gas/oil ratio, and there exists the phenomenon of retrograded condensation during the gas recovery progress (Liu et al., 2013). Its high molecular weight is derived from the quantity of heavy ends (Sutton, 1985). The phase behavior of the gas condensate fluid is strongly dependent on the thermodynamic conditions of the hydrocarbon mixture (Arabloo et al., 2013). The heavy ends will pour out liquid via retrograde condensation when the pressure falls below the dew point pressure (DPP), which is defined as the pressure at which a massive amount of the vapor phase exists in equilibrium with an infinitesimal amount of the liquid phase (Shokir, 2008). In some cases, this phenomenon should be avoided because it may lead to the formation of hydrocarbon condensates, which can cause damage to production facilities and transmission pipelines and result in a rapid decline in well productivity (Galatro and Marín-Cordero, 2014; Mokhtari et al., 2013). Moreover, to predict the changes in retrograde gas condensate composition and calculate the pressure depletion behavior of gas condensate reservoirs, the first step is to match the DPP predicted by the equation of state (EoS) to the experimental value (Elsharkawy and Foda, 1998). Hence, it is significant to accurately determine the DPP for gas condensate reservoirs.

Different approaches have been proposed to predict the DPP, including experimental measurement (Sun et al., 2012; Louli et al., 2012), empirical correlations (Elsharkawy, 2002; Nemeth and Kennedy, 1967; Shokir, 2008; Wang et al., 2013), thermodynamic models (Bonyadi et al., 2014; Daqing and Tianmin, 1997; Nasrifar and Bolland, 2006; Nasrifar et al., 2005) and other intelligent approaches (Arabloo et al., 2013; Elsharkawy and Foda, 1998;

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Rostami-Hosseinkhani et al., 2014). The experimental way can provide accurate and reliable results (Arabloo et al., 2013). However, the experimental determination of DPP at the reservoir temperature for the gas condensate fluid is relatively expensive and time consuming (Sage and Olds, 1947; Grieves and Thodos, 1963; Pedersen et al., 1988; Elsharkawy, 2002). The application range of empirical correlations is often limited to the experimental conditions used for building the correlations and the complexity and range of gas condensate parameters used (Liu et al., 2013; Sun et al., 2012). Intelligence tools usually have the following shortcomings: complicated training and testing steps are required. Therefore, the thermodynamic model based on the EoS, as an alternative approach to calculate DPP, is regarded as a better solution (Louli et al., 2012; Nasrifar et al., 2005; Sun et al., 2012). It is applicable for both the liquid and vapor phases of hydrocarbon systems. Although numerous EoSs have been reported in the literature, the two-parameter cubic EoSs are still reliable and convenient for estimating the lean and rich natural gas properties (Ahmed, 1988; Mørch et al., 2006; Nasrifar and Bolland, 2006). The Peng and Robinson (1976) (PR) EoS, which has a simple structure with known critical properties and acentric factor for all components, has been extensively employed to describe the phase behavior of petroleum fluids (Rodriguez and Hamouda, 2010). The EoS with classical mixing rules will reasonably perform equilibrium predictions when the binary interaction parameters (BIPs) are suitably determined (Tabrizi and Nasrifar, 2010). Moreover, several modified versions of the PR EoS have been developed to improve the predictive ability for hydrocarbon gas systems (Daridon et al., 1993; Forero and Velásquez, 2012; Haghtalab et al., 2011; Stryjek and Vera, 1986; Twu et al., 1995). These modified EoSs can obtain satisfactory results when predicating the PVT properties of a pure component, some binary mixtures and a few gas condensate samples, but their adaptabilities for describing the DPP for more different gas condensates have not been examined.

Previous studies conducted by several researchers have demonstrated that accurate prediction of the DPP for gas condensate not only relies on the appropriate EoS with mixing rules but also depends on the suitable characterization methods for the plus fraction (Daqing and Tianmin, 1997; Elsharkawy, 2002; Galatro and Marín-Cordero, 2014; Nasrifar et al., 2005). Gas condensate often presents the components that have carbon numbers equal to or greater than 7 as plus fractions (C_{7+}) (Bonyadi and Esmaeilzadeh, 2007). The heavy ends of gas condensate fluids are considered as having a dominant role in determining the phase behavior, and their molecular weight, density and relative amount have great influence on the DPP (Elsharkawy, 2002; McCain and Alexander, 1992). This will lead to erroneous predictions if the plus fraction is used directly as one component in EoS calculations (Al-Meshari and McCain, 2007). Thus, it is necessary to split the plus fractions into a series of pseudo-components via splitting methods (Whitson, 1983). Recently, a new molar distribution function called the four-coefficient model (4CM) for the characterization of gas condensate fluids was introduced, and its parameters have been correlated by different authors (Ghasemi et al., 2014; Hosein and McCain, 2009; Hosein et al., 2008, 2012). This model is based on the two-coefficient method described by Ahmed et al. (1985). After the analytical extension of the gas condensate plus fraction, Ghasemi et al. (2014) indicated that the 4CM has the following shortcomings: the four coefficients are not universal and need to be determined for each fluid type, and composition analysis should be achieved at least to C_{14+}. However, it was recently evaluated and compared with other splitting methods to verify whether it will produce a discontinuity at C8 and C13 for gas condensate samples (Ghasemi et al., 2014; Hosein et al., 2012). With respect to the two-coefficient method, the accuracy of the 4CM when determining the DPP for various gas condensate samples has not been studied.

Moreover, to obtain the critical properties and acentric factor of every pseudo-component, characterization methods should be applied after the step of splitting. A number of correlations for calculating the critical properties, boiling point temperature, specific gravity and acentric factor have been proposed by different researchers in the literature (Edmister, 1958; Hosseinifar and Jamshidi, 2014; Jamialahmadi et al., 2012; Kesler and Lee, 1976; Pedersen et al., 1988; Riazi and Al-Sahhaf, 1996; Riazi and Daubert, 1987; Twu, 1984; Watanasiri et al., 1985; Whitson, 1982). The results show that even small errors associated with critical properties and the acentric factor can greatly affect the predicted thermophysical properties of fluids (Rahimpour et al., 2013; Riazi et al., 1998). Limited by the application range, both the splitting and characterization methods should be compared and optimized before they are used to establish the thermodynamic model to predict the DPP for gas condensate systems.

In this work, for the sake of accurately predicting the DPP for various gas condensates, a thermodynamic model based on a modified PR EoS, named MPR2 EoS, in which two temperature functions, i.e., an alpha function for the parameter a together with a linear temperature function for the parameter b, are implemented (Haghtalab et al., 2011), is presented. The following impact factors are considered: EoS, mixing rules with BIPs, plus fraction splitting method, critical properties and acentric factor correlations for pseudo-components. Furthermore, the MPR2 EoS is compared with ten EoSs, including eight PR families of equations, i.e., PR, PRSV (Stryjek and Vera, 1986), PRT (Twu et al., 1995), PRSF (Forero and Velásquez, 2012), PRHF (Forero and Velásquez, 2012), PRGF (Forero and Velásquez, 2012), PRTBD (Daridon et al., 1993) and PRJF (Forero and Velásquez, 2012), and two other modified versions of the SRK (Soave, 1972) equation, i.e., SRKMCC (Coquelet et al., 2004) and SRKNB (Nasrifar and Bolland, 2004). Additionally, a comparison between the model and four empirical correlations, i.e., Nemeth and Kennedy (1967), Elsharkawy (2002), Shokir (2008) and Wang et al. (2013) is provided to evaluate the accuracy and reliability.

2. Model establishment

The DPP prediction model established in this work for gas condensate is composed of three parts: a modified two-parameter cubic EoS, mixing rules with BIPs, and characterization methods for the heavy ends.

2.1. The modified Peng–Robinson EoS

Haghtalab et al. (2011) modified the PR EoS by introducing a new alpha function and a temperature dependent function for covolume, b, in its pressure explicit function. For the three gas condensate samples studied in the text, the modified equation can obtain better DPP calculation accuracy than SRK and PR EoSs at the pressure and temperature ranges of 33.47–46.07 MPa and 390.5–450.3 K, respectively. The modified equation is expressed as follows:

$$P = \frac{RT}{v-b} - \frac{a(T)}{v(v+b)+b(v-b)} \tag{1}$$

where the attractive and repulsive parameters, a and b, for pure components can be determined using the critical properties as follows: